Late Pleistocene History and Stratigraphy of Niagara Falls

Senior Thesis

presented in partial fulfillment of the requirements
for the degree of Bachelor of Science

by

Raymond Kennedy

1986

Advisor: Dr. Utgard

ABSTRACT

Niagara Falls owes its origin to Pleistocene glaciation. As the glaciers retreated northward a sequence of glacial lakes and outlets developed. With the opening of the Mohawk outlet to the Hudson, waters from glacial lake Algonquin subsided to below the Niagara Escarpment. This led to the formation of the Niagara River and gorge. The volume of water discharging through the river has varied considerably, ranging from 15% to 110% of present flow, with the opening or closing of alternate drainage outlets.

The falls has receded 11.2 km up river from its point of origin, Lewiston N.Y.. The retreat of the falls is the result of the interaction of water with the underlying sedimentary rock. In the past the falls retreated at a rate of 0.9 - 1.8 meters per year. Today, water is being diverted away from the falls for hydroelectric power and the rate of retreat has slowed to 0.3 - 0.6 meters per year.

Introduction

Niagara Falls has existed for the past 12,600 years. During this period it has receded 11.2 km upriver to its present location. This paper will look at the conditions that favored the formation of the falls; the dynamics of the falls recession; correlate specific sections of the gorge with early Great Lakes history and describe the sedimentary rocks that outcrop in the gorge.

TABLE OF CONTENTS

Table of Illustrations

Topography and Location

The Niagara Falls area is located in the lowland bordering the southern shore of Lake Ontario. It is a region of low relief except for the Niagara escarpment, Beach Ridge and Niagara River gorge. The elevation in the area changes from 206 meters above sea level in Orleans County to 75 meters above sea level along the shore of Lake Ontario.

The Niagara escarpment crosses the area in an east-west line extending from the Niagara River on the west to the Brockport area in the east. The escarpment is 60 meters high along the Niagara gorge and diminishes eastward to a broad, gently sloping incline. (See Fig. 1)

The Beach Ridge represents the former shoreline of glacial Lake Iroquois.

Description of Falls

Niagara Falls consists of two falls. The Canadian Falls (Horseshoe Falls) and the American Falls (Bridal Veil Falls). The two are separated by Goat Island. The Canadian Falls is the larger of the two and discharges 90% of the flow of the Niagara River. It is about 790 meters long and 49 meters high. The American Falls measures 305 meters long and 51 meters high. The average flow over the falls is 150,000 cfs (cubic feet/second).

Niagara River

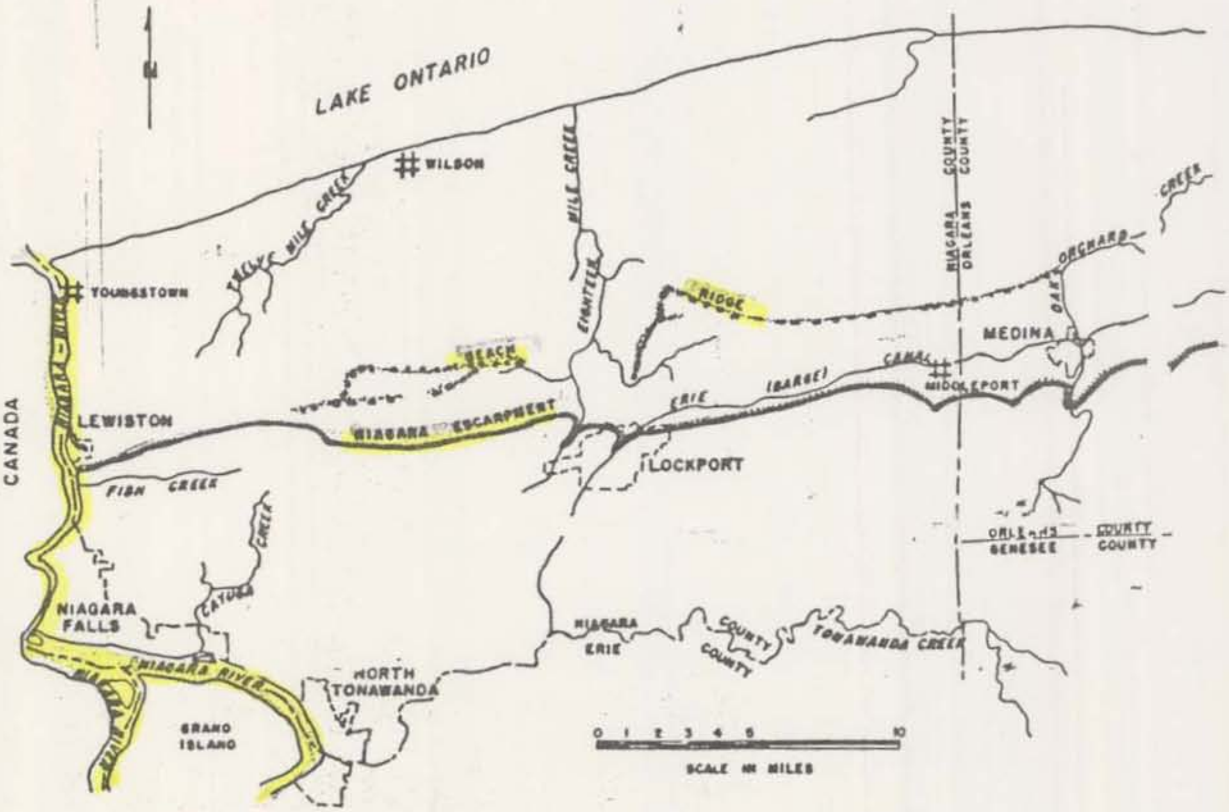


Figure 1.--Physical features of the Niagara Falls area.

The Niagara River is 55 km. long, beginning from Lake Erie at Buffalo, New York and flowing northward into Lake Ontario. During its course the Niagara makes a descent of 99 meters, about half of which occurs at the falls. It is the main drainage outlet of the upper Great Lakes. This causes the flow of water in recent times to remain relatively constant. In the past 80 years, however, man has diverted a large volume of water from reaching the falls (during certain times of the day) for use in producing hydroelectric power. The diverted waters re-enter the Niagara farther down river .

Geology of the Niagara Gorge

The geology of the Niagara Falls region is well understood because of its simplicity and excellent outcrops along the Niagara River gorge and the Niagara escarpment. The stratigraphy in this report will be limited to those outcrops within the Niagara River gorge.

The strata in the Niagara Falls region consists of nearly flat lying (less than 1 degree dip to the south) sedimentary rocks that are Ordovician (Queenston Shale), and Silurian (Medina, Clinton, Lockport groups). (See diagrams 2 and 3)

Description of Rock within the Niagara Gorge

QUEENSTON SHALE

The Queenston Shale is Late Ordovician, Cincinnatian in age. Its

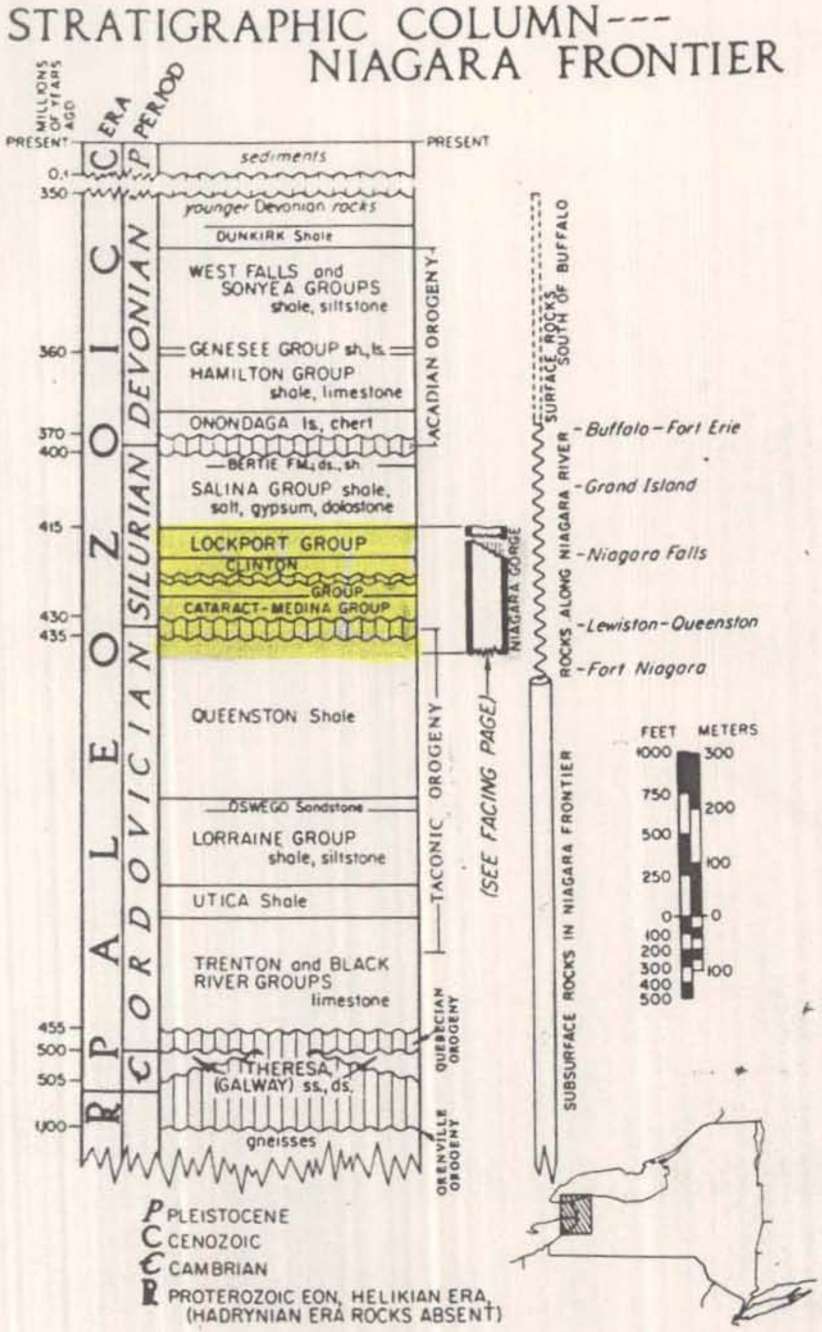


FIG 2.

THE FORMATIONS OF THE NIAGARA GORGE IN RELATIONSHIP WITH THE STRATIGRAPHIC COLUMN OF NIAGARA FRONTIER.

Tesmer, I., 1981 Colossal Cataract: SUNY Press p. 78-80.

STRATA ALONG NIAGARA GORGE

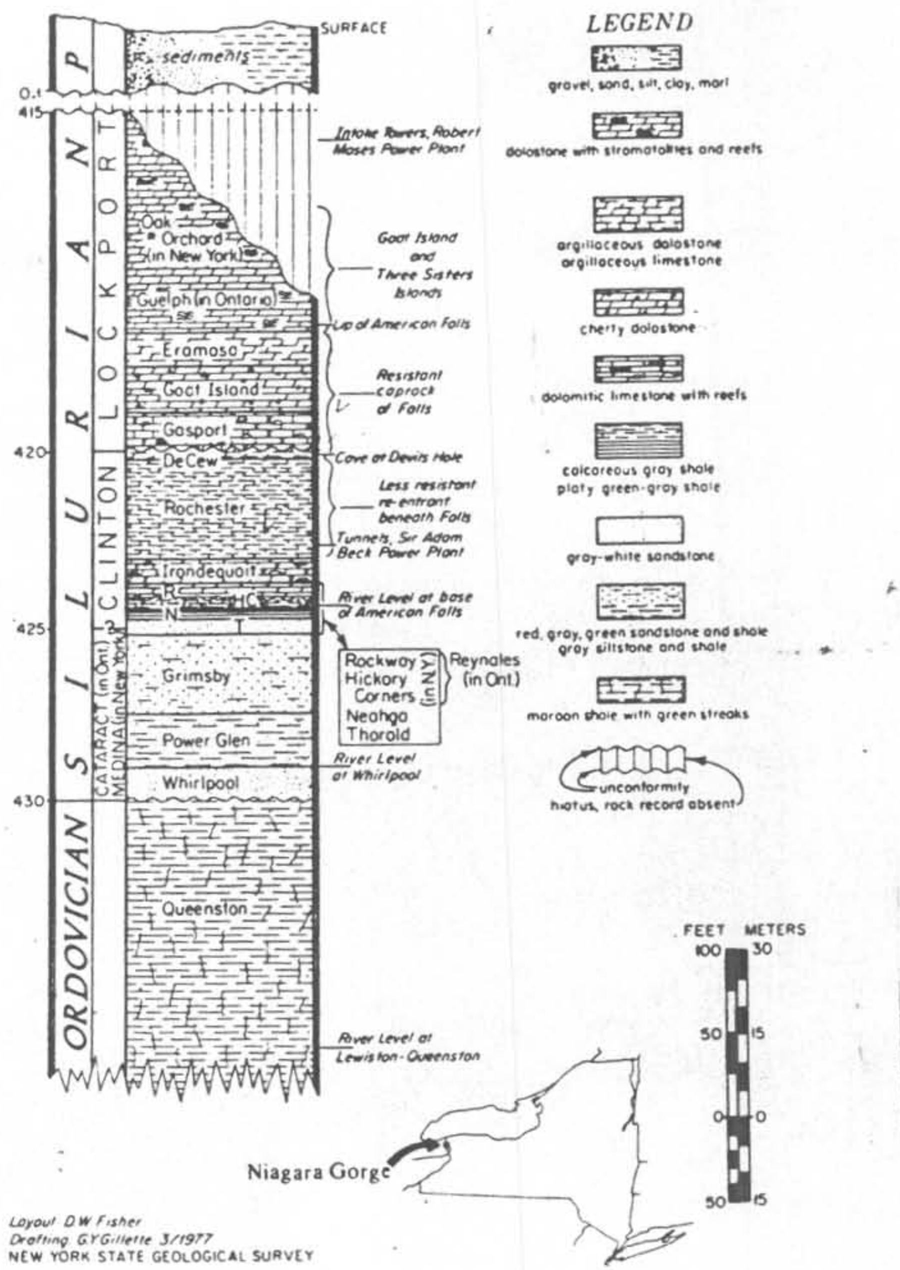


Fig. 3

thickness varies between 213 and 335 meters. Thirty-six meters are exposed along the gorge in Queenston, Ontario. The unit thins to the north and west of the Niagara River.

Lithology: The Queenston Shale is purplish red in color. It is an argillaceous rock with indistinct shaly bedding. The unit is composed mainly of clay minerals (95%), Quartz (4%) as silt, and 1% carbonates. Near the contact with the lower Silurian, thin green seams follow joints and bedding. These seams represent the percolating effect of ground-water in changing red ferric oxide to green ferrous oxide. This reduction process is caused by humic acids (Fisher).

The depositional environment represented the landward side of a huge delta. Material was being supplied by erosion from an emergent eastern land during the late stage of the Taconic Orogeny.

The Whirlpool sandstone overlies unconformably the Queenston Shale.

MEDINA GROUP

The Medina group represents the lower Silurian. The group is divided into four formations, the Whirlpool Sandstone, Power Glen Shale, Grimsby Sandstone and Thorold Sandstone. It is a relatively thin stratigraphic unit that is characterized by white, gray, pink, red and mottled sandstones and siltstones with small amounts of red, green and gray shales.

Description of Medina Group

a) Whirlpool Sandstone

The Whirlpool Sandstone's thickness varies in the Niagara gorge betweem 7.6 to 4.6 meters and pinches out and disappears to the northwest. In the east it is difficult to distinguish beyond Medina, New York.

Lithology: The Whirlpool Sandstone is a medium to coarse grained, very light gray to white pure quartzose sandstone (93-97% quartz). Occasional inclusions of flat pebbles of green shale are seen. The unit is medium to thick bedded. Large scale cross bedding occurs throughout the unit. Other structural features include ripple marks and mud cracks along basal contact with Queenston Shale (Grabau).

The Whirlpool is the product of an aeolian sand spread over sun cracked mud flats.

b) Power Glen Shale

The Power Glen Shale thickness varies from 10.4 to 11 meters within the gorge. The unit thin to the east and cannot be identified beyond Pekin, New York. Toward the west the unit differentiates into the Manitoulin Dolostone and Cabot Head Shale.

Lithology: The Power Glen Shale is comprised of finely laminated gray and greenish shales interbedded with sandstones dolostones and siltstones. Dark gray shales with thin calcareous siltstones comprise the lower portion whereas the upper portion has a greenish cast (Bolton). Ripple marks and cross bedding is observed.

c) Grimsby Sandstone

The Grimsby Sandstone thickness within the gorge varies between 12.8 to 15.8 meters. Towards the east it thickens to 21.8 meters and in the west pinches out and cannot be identified beyond Hamilton, Ontario.

Lithology: The Grimsby sandstone is divided into three facies. The lower facies is a pink, white and pale green mottled siltstone or sandstone interbedded with green shale pebbles. Also observed are red shale and red sandstone interbeds in this lower facies. The middle facies consists of medium to thick bedded red and pink hematite sandstones with large scale cross-bedding. The upper facies is a red crumbly shale with a few greenish-gray shale beds (Williams).

The Grimsby sandstone represents an intertidal zone with barrier beach and lagoon deposits.

d) Thorold Sandstone

The Thorold Sandstone ranges in thickness betweem 1.4 to 3 meters along the gorge. To the east it thins and locally it has been eroded away. Toward the west it thickens.

Lithology: The Thorold Sandstone is a massive, resistant, light gray quartzose sandstone to siltstone. The unit is composed of 70% quartz, 20% argillaceous material, 6% feldspars and accessory minerals (Alling). The Thorold Sandstone represents an ancient shore of a bay or sea.

CLINTON GROUP

The Clinton group represents the middle Silurian. This group is composed of a great variety of sedimentary rocks that change rapidly in lithology and fossil content. The Clinton group contains the (A) Neahga Shale, (B) Reynales Formation, (C) Irondequoit Limestone, (D) Rochester Shale and (E) Decew Dolostone.

A) Neahga Shale

The Neahga shale thickness varies from 1.8 and 2.1 meters in the Niagara gorge. It disappears eastward and towards the west can be traced to St. Catherines, Ontario.

Lithology: The Neahga shale is a soft slightly silty, calcareous gray to green shale. The lower 3 meters being harder, more arenaceous and more calcareous then the rest of the shale (Sandford).

The Neahga shale represents the initial deposit of the lower Clinton sea as it re-invaded the area and the eastern strand line transgressed from east to west (Sandford).

B) Reynales Formation

The Reynales Formation is divided into the Hickory Corners Limestone and Merritton Limestone members. In this report only the Hickory Corners Limestone will be discussed, the Merritton Limestone do not occur in the Niagara gorge.

Hickory Corners Limestone

The Hickory Corners Limestone thickness varies between 0.6 and 1.3 meters in the gorge.

Lithology: The unit is a thin bedded, dark gray, bioclastic, argillaceous resistant limestone having numerous shale breaks and lenses. A 4-7 cm layer containing phosphate nodules and shale inclusions occurs at the base.

The Hickory Corners limestone represents a shallow, rough water sea deposit.

C) Irondequoit Limestone

The Irondequoit Limestone thickness varies between 4.6 and

6.3 meters in the Niagara gorge. It forms a resistant ledge in the gorge. The unit thins towards the west and merges into the base of the overlying Gasport Formation. Toward the east the unit thickens and grades into the Willowvale Shale.

Lithology: The Irondequoit Limestone is a crinoidal limestone. It is massive to poorly bedded and contains crystals of pink calcite along with pyrite, gypsum and pyrolusite (Sandford).

The Irondequoit is highly fossilferous and contains a wide variety of fossils in addition to crinoids, including brachiopods, bryozoans and corals.

D) Rochester Shale

The Rochester Shale thickness ranges from 16.8 to 19.8 meters in the gorge. The unit thins towards the west and dissappears near Hamilton, Ontario. Toward the east it thickens and grades into the Herkimer Sandstone.

Lithology: The Rochester Shale is a dark bluish to brownish gray, calcareous, highly fossiliferous shale with atypical argillaceous limestone layers (Clarke and Schuchert).

The Rochester Shale yields more species of fossils then any other single Silurian formation. These fossils include bryozoans, crinoids and trilobites.

E) Decew Dolostone

The Decew Dolostone is considered by many to be the basal member of the Lockport group. In this report I am including the Decew in the Clinton Group.

The Decew Dolostone thickness ranges from 1.7 to 3.7 meters in the

Niagara gorge. It can be identified as far west as Hamilton, Ontario and east as far as Rochester, New York.

Lithology: The Decew is a finely crystalline dolostone. Dolomitic shales are common in the lower portion while the upper portion exhibits thicker bedded, fine grained silty dolostone. In the lower portion the Decew exhibits convolute structure. Compaction slickensides are well developed in irregular shaly partings. Caves and other solution features are common.

LOCKPORT GROUP

The Lockport group is middle Silurian and consists of the (A) Gasport Limestone, (B) Goat Island Dolostone, (C) Eramosa Dolostone and (D) Oak Orchard Dolostone. A complex joint system occurs within the Lockport group that has been caused by the stress of uplift and episodes of glaciation.

A) Gasport Limestone

The thickness of the Gasport Limestone varies between 4.6 and 13.6 meters in the gorge.

Lithology: The Gasport Limestone is a coarse grained, low soluble limestone or dolomitic limestone of blue to gray color. Bedding is massive with discontinuous shale partings. Vugs filled with gypsum are common.

Fossils are abundant and well presersved in the less dolomitized beds. These fossils are primarily brachiopods, corals, bryozoans and stromatopoids (Zenger).

B) Goat Island Dolostone

The thickness of the Goat Island Dolostone varies between 5.3 and 7.9 meters in the gorge. The unit extends from Hamilton, Ontario to Albion, New York.

Lithology: The Goat Island Dolostone is a medium to fine crystalline, thick to massive bedded dolostone, with a sugary texture. The upper portion is characterized by abundant chert nodules. Vugs are common throughout and they contain gypsum, sphalerite and calcite. Fossils are uncommon and not well preserved.

C) Eramosa Dolostone

The thickness of the Eramosa Dolostone varies between 4.1 and 4.6 meters in the gorge. The unit ranges from northern Michigan in the west to Lockport, New York in the east.

Lithology: The Eramosa Dolostone is dense, finely crystalline, thin to thick bedded dolostone. The bedding surface is commonly coated with carbonaceous material and fresh surfaces emit an oily smell. Vugs containing calcite, gypsum, sphalerite, galena and dolomite are common. Fossils are uncommon and not well preserved.

D) Oak Orchard Dolostone

The thickness of the Oak Orchard Dolostone is between 36.5 and 38 meters. The lower 0.5 to 1.2 meters forms the resistant caprock of the American Falls.

Lithology: The Oak Orchard Dolostone is medium to thick bedded, medium grained, bituminous stylolitic dolostone. Carbonaceous shaly partings and vugs are common throughout the unit. Stramatolite zones and poorly preserved stromatoporoids and corals are characteristic of this unit.

Niagara Falls and the Pleistocene

Niagara Falls owes its origin to late Pleistocene glaciation. Before continental glaciers first covered the land there were no Great Lakes or Niagara River. The Great Lakes now fill depressions that were scoured out by the progression of ice along ancient river valleys. The last glaciation, the Wisconsin (Late Wisconsin, Cary) shaped the modern Niagara River.

Evidence from moraines, striae, drumlins and interpretation of heavy mineral provenance shows that western New York was strongly affected by the Erie glacier lobe. This lobe was fed by an ice sheet northeast of Lake Ontario. During its soutwesterly advances, ice also spilled out southeasterly from the Erie basin into western New York.

As the ice began retreating across the basins of the Great Lakes, the meltwaters became trapped between the high ground around the basin and the edge of the glacier. This left an ever changing succession of lakes (Fig. 4 and 5). Such lakes occupied the Erie and Ontario basins and they changed in size and shape depending on ice retreat (or advance) and opening (or closing) of outlets at different elevations (Terasmae). These events resulted in a sequence of lake stages. Some important lake stages include Whittlesey, Warren, Algonquin and Tonawanda.

Glacial Lake Whittlesey evolved into Glacial Lake Warren when the waters were allowed to escape westward through the Grand River Channel

LAKE STAGES

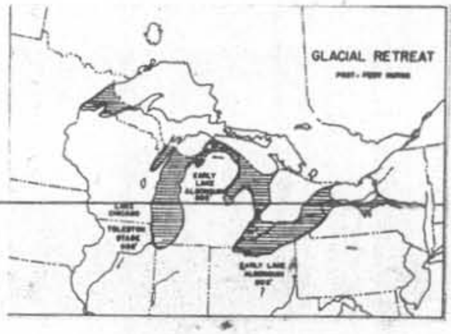
Lake Whittlesey

Lake Warren

Marcellus Channel

Lake Algonquin

Hudson Outlet



early Lake Erie

Niagara River

ST. Lawrence Outlet

Fig. 4

Trent River Outlet

Valder's ice retreat

Hough, J.L., 1963, The Prehistoric Great Lakes of N. American: Am. Scientist. v. 51, p. 84-109.

Fig. 4

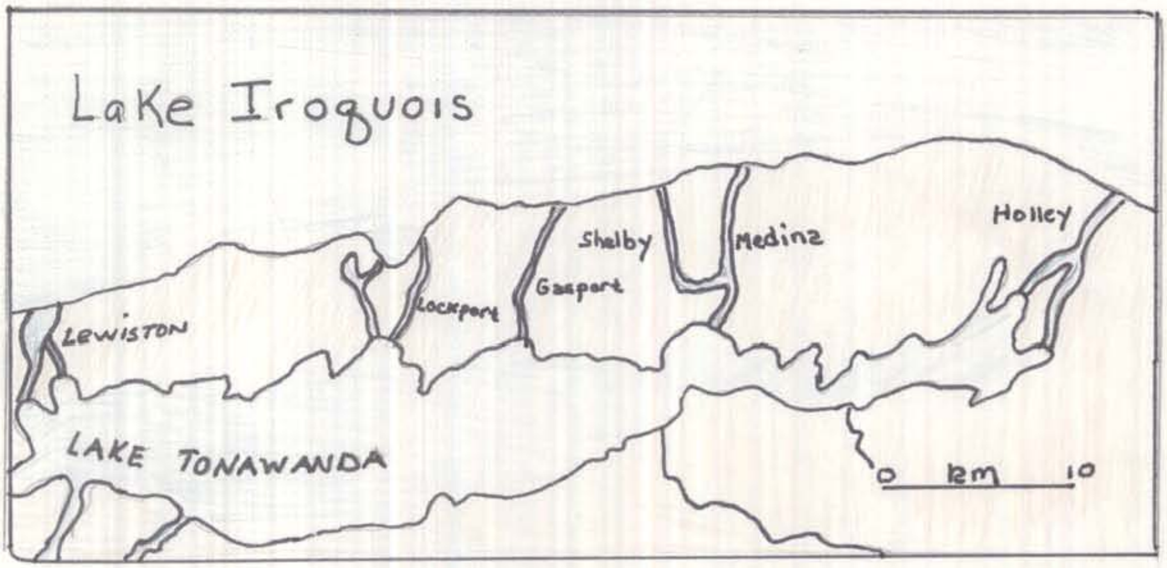


Fig. 5 LAKE TONAWANDA and its spillways

into Lake Chicago. As the ice further retreated it opened an outlet near Syracuse. The Marcellus Channel allowed water to flow eastward and Lake Warren evolved into Lake Algonquin. Further ice retreat opened the Mohawk outlet to the Hudson. This led to a gradual lowering of the lake level to below the Niagara escarpment. This caused the formation of two lakes, early Lake Erie and Iroquois and the formation of the Niagara River, gorge and falls at Lewiston, New York.

The drop in water level uncovered the Niagara and Onondaga escarpments. Water coming from the newly formed Detroit, St. Clair and Niagara Rivers were trapped between the two escarpments forming Lake Tonawanda. The Lake extended 93 km east of Niagara Falls to Holley, New York (See Fig. 6) and averaged 7.2 km in width. Its depth was about 10 meters.

The initial Niagara River flowed into Lake Tonawanda. Lake Tonawanda was a peculiar lake in that it had five separate spillways, all of them draining northward and pouring over the escarpment into Lake Iroquois. Location of these spillways are at Lockport, Gasport, Medina, Holley and Lewiston. Because of isostatic tilt, spillways at Lewiston and Lockport carried most of the discharge. It was at Lewiston that the process of gorge cutting began about 12,600 B.P. The Lewiston spillway eventually evolved into the single drainage connection between Lakes Erie and Ontario and concentrated outflow began major cutting of the Niagara gorge. This process is still continuing today, 11.2 km upstream.

Dynamics of Falls Recession

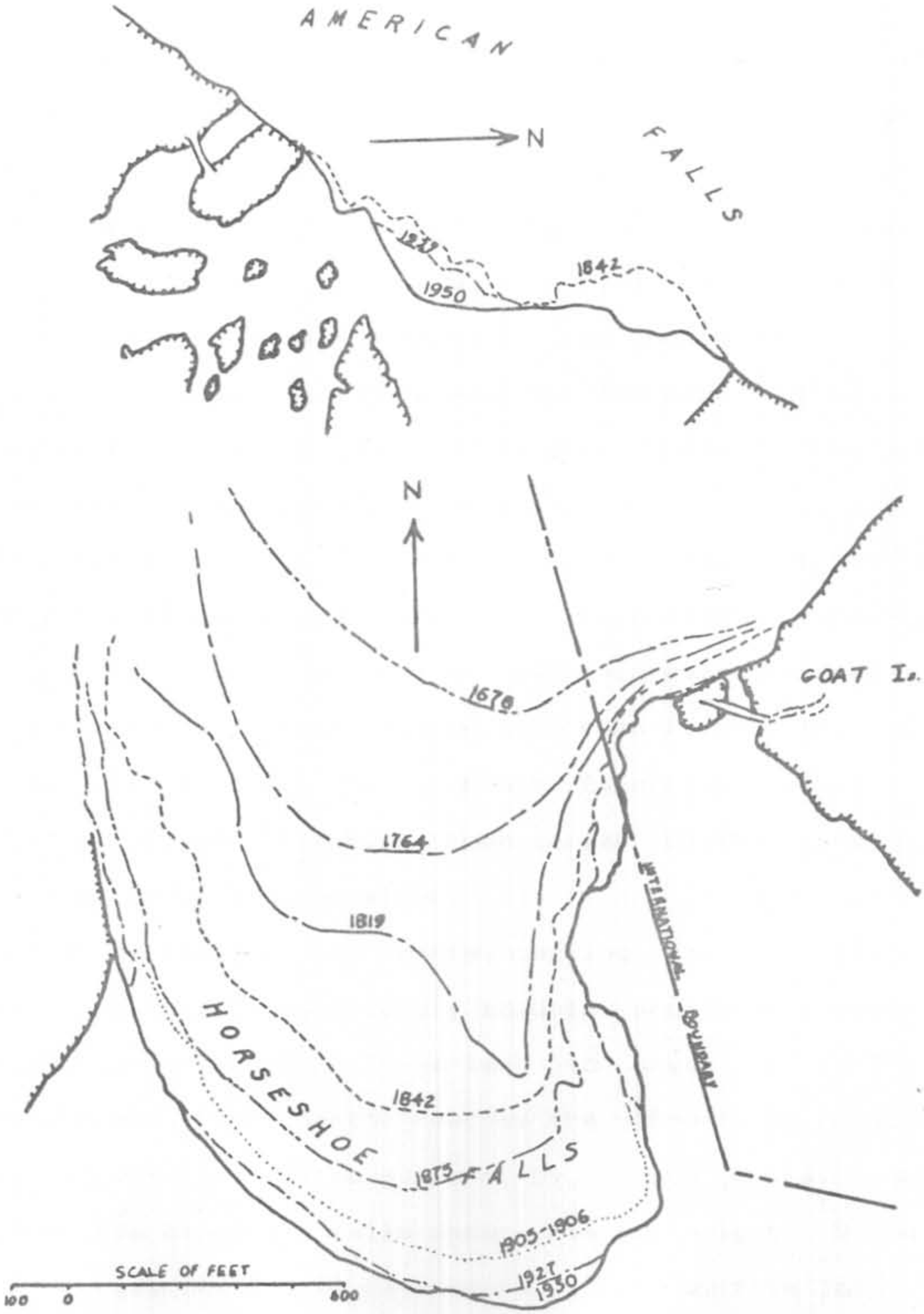


Figure 6. Comparative crestlines of Horseshoe and American Falls. After International Niagara Falls Engineering Board, 1953.

In 1969 the American Falls was dewatered by the Army Corps of Engineers. In their findings they found a complex system of joints in the Lockport Dolostone whose frequency increased toward the face of the falls. Ground water flowing through these joints causes hydrostatic pressure to build. They also observed the following: freeze/thaw, widening of joints by solution, the Rochester Shale were more resistant when they were kept wet, the force of falling water broke rock at the base of the falls and during rock slides the surrounding rocks became more susceptible to erosion.

The recession of Niagara Falls is the result of the interaction of water with the underlying strata. The Lockport Dolostone is hard and resistant to erosion because of its chemical composition ($CaMg(CO3)2$). When a stress is applied however, the rock is brittle, causing fractures (joints) to occur. The Lockport Dolostone contains vertical and horizontal joints that have been caused by the stress of uplift and several episodes of glaciation.

Water infiltrates the joints, causing the joint cracks to widen by solution (dolostone is slightly soluble and forms carbonic acid) and by hydrostatic pressure. These tend to break the rock apart. Water flowing down these joints reaches the underlying Rochester Shale, it then removes the shales support by erosion. The Lockport Dolostone becomes undermined and falls under its own weight. Since the formation of the gorge, the falls, have moved 11.2 km by this joint block by joint block recession.

The rate of recession in the past varied between 0.9 and 1.8 meters per year. Today, with water being diverted for hydroelectric power the recession rate has decreased to 0.3-0.6 meters per year.

Niagara Gorge

The profile of the gorge depends on the volume of water discharging through the Niagara River and the underlying strata. The volume of water has varied considerably, ranging from 15% to 110% of present flow. The changes in flow resulted from the opening (or closing) of a number of glacial outlets, that diverted part or all of the upper Great Lakes waters from reaching Lake Erie and the Niagara River. Evidence for the variation in flow can be seen within the gorge itself (such as height and width of gorge). The gorge can be divided into five sections based on the Great Lakes history (Hough). Hough (1963) divided the gorge as follows: (1) Cataract Basin and Lewiston Branch Gorge Sections (2) Old Narrow Gorge Section (3) Lower Great Gorge Section (4) Whirlpool Rapids Section and (5) Upper Great Gorge Section.

(1) Cataract Basin and Lewiston Branch Gorge Sections

The gorge originated at Lewiston, New York where waters from the Niagara River flowed over the Niagara Escarpment initiating gorge cutting. This portion of the gorge originated with the formation of Lakes, Tonawanda, Erie, and Iroquois. Discharge was moderate at Lewiston

The Cataract Basin is a remnant of the original plunge pool. The scars in the rock caused by the plunge pool and old river edge can be traced along both sides of the gorge (Terasmae).

(2) Old Narrow Gorge Section

Ice retreat opened the Trent River outlet at Kirkfield, Ontario and the waters in the upper glacial Great Lakes by-passed the Port Huron outlet into early Lake Erie. The Niagara River only carrying the discharge from early Lake Erie cut a narrow and shallow gorge (Hough).

(3) Lower Great Gorge Section

The Valders ice advance closed the Trent River outlet. Discharge from the upper Great Lakes flowed through Port Huron into Lake Erie. The increased volume of water flowing over the falls cut a deeper and wider gorge.

Along the southern end of the lower great gorge the river abruptly makes a 90 degree bend. This resulted when the Niagara Gorge intersected the buried St. Davids Gorge at right angles. The buried, Pleistocene deposits were less resistant to erosion and eroded at a much quicker rate then the rock on the opposite side of the gorge, causing the gorge to pivot 90 degrees and widen.

The buried St. Davids Gorge extends from the Whirlpool Basin to the town of St. Davids, Ontario. It then extends northward to the lower Niagara. The gorge was once a major outlet. Its depth and width indicate that at one time its discharge was comparable to that of the present Niagara. The gorge became filled with a sequence of glacial and nonglacial deposits during middle and late Wisconsin time.

(4) Whirlpool Rapids Section

After the falls had cut through the Whirlpool Basin, the flow of water over the falls, plus the height of the falls began to decrease. This was caused by two factors 1.) The width of the dolostone shrank from 25 meters to 6 meters, 2.) The Trent River outlet and Northbay outlet became opened when the Valders ice sheet retreated northward, diverting the waters away from Lake Erie, and the Niagara River.

The gradual reduction of water from the upper Great Lakes caused depth of the Niagara Gorge to decrease by 16 meters. The rapids were created by this drop.

The Trent River outlet was abandoned when isostatic rebound uplifted the area. The Northbay outlet remained opened.

(5) Upper Great Gorge Section

The Northbay outlet was abandoned due to isostatic rebound. The upper Great Gorge began cutting a deeper and wider gorge as waters from the upper Great Lakes flowed through the Chicago outlet and Port Huron outlet into lake Erie.

The Chicago outlet, resting on bedrock, could not cut a deeper channel; however, the Port Huron outlet to Lake Erie, resting on till, was cut down and further concentrated the flow through Lake Erie and over the falls (Farrand).

Future of the Falls

As the Horseshoe falls continues to recede southward it will eventually intercept the waters going to the American Falls, forming a single waterfalls. Beyond this event, the falls future is debated. Some feel the falls will recede all the way to Lake Erie; others believe it will be transformed into a series of rapids that will stretch from Lake Erie to Lewiston; and still others argue that uplift in the north will cause the upper Great Lakes to abandon the Port Huron outlet and form a new outlet through the Illinois River. The flow of water through the Niagara River would then be limited to discharge from Lake Erie and would vary considerably, depending on the climatic conditions around the Lake Erie Basin.

References

1. Alling, H.L, 1936, Petrology of the Niagara Gorge Sediments: Proc. Roch. Acad. Sci. v.7, n.7 p. 189-203

2.Bolton, T.E, 1953, Silurian Stratigraphy of Niagara Escarpment, Canadian Geol. Surv. Paper 53-23

3. Buehler, E.J.& Tesmer, I.H., 1972,Geology of Erie County N.Y.: Buffalo Soc. Nat. Sci. Bull. 21 p.118-120

4. Calkin, P.E., 1966, Late Pleistocene History of Northwestern N.Y.: Geology of Western New York Guide Book p.58-68

5. Encyclopedia Britanica, Niagara Falls p325

6. Farrand,W.R., 1962, Post Glacial Uplift in North America: Am. Jour. Sci., v. 260 p. 181-191

7. Fisher, D.W., 1954, Stratigraphy of Medina Group, N.Y and Ont.: Bull. Amer. Assoc. pet. Geol v.38 n.9 p.1979-1996

8. Grabau, A.W., 1908, North American Silurian System: Jour. Geol. v.178 p.209-259

9. Hough,J.L., 1963, The prehistoric Great Lakes of N. America: Am. Scientist, v. 51, p. 84-109

10. Sandford,J.T., 1953, The Clinton in Western N.Y.: Jour. Geol.v.43 p.167-183

11. Schuchert, C., 1914, Medina and Cataract Formations of the Silurian in N.Y. and Ont.: Geol.Soc. Bull. v.25 p.277-320

12. Terasmae, J., Clarke, J.R., Karrow, P.F., 1961, The age of Lake Iroquois and Ontario: Jour. Geol. v.69 p.659-667

13. Tesmer, I.,1981 Colossal Cataract: SUNY Press p.78-80

14. Williams, M.Y., 1903, Stratigraphy of the Niagara Escarpment: Canadian Geol. Surv. sum. rep. p.178-188

15. Zenger,D.H., 1965, Stratigraphy of the Lockport Formation in N.Y.: N.Y. State Museum and Sci. Serv. Bull., v.46 n 404